Magnetic Tunnel Junctions & Spin Torque Nano-Oscillators

Robert Costanzo and Jacob Breiholz

Our Map

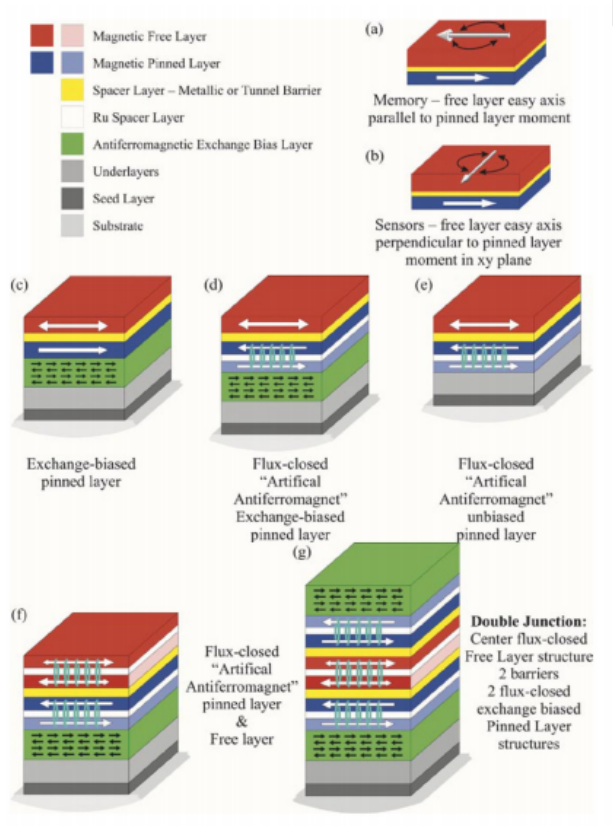
MTJ Basics

STNO Theory

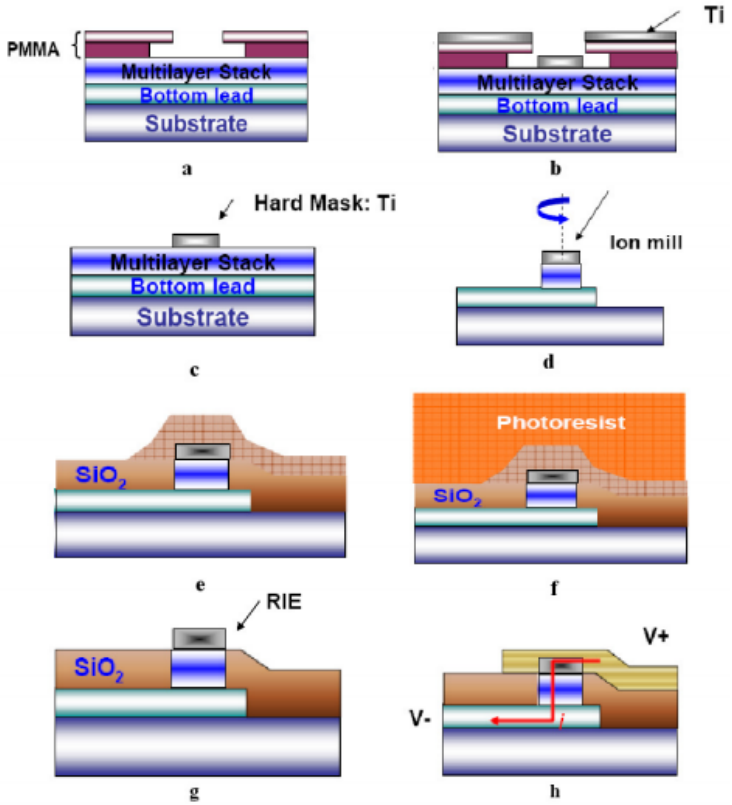
Applications

MTJ Basics

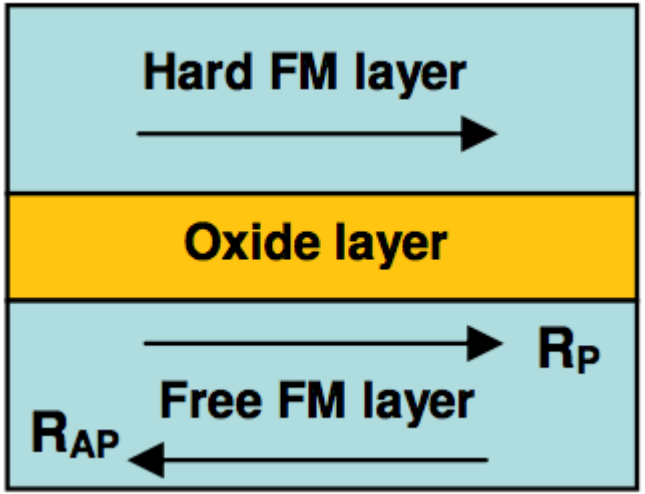
MTJ's come in a variety of sizes and typologies suited for different applications.



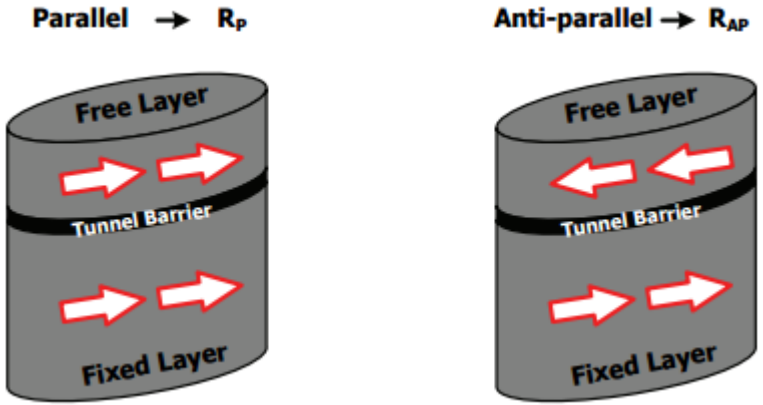
MTJ's are mostly compatible with traditional foundries.

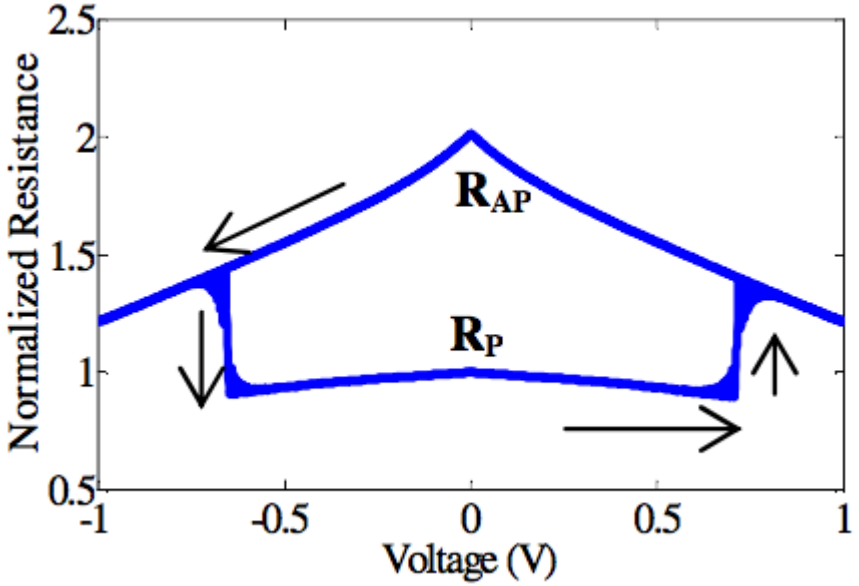


MTJs consist of several ferromagnetic and insulator layers.

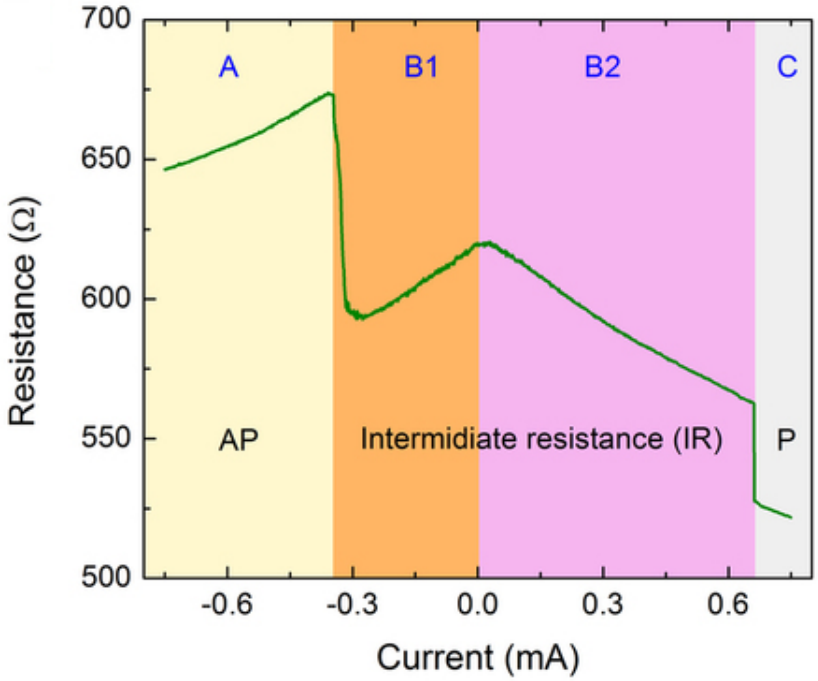


MTJs can operate in two states, switching between effective resistances.

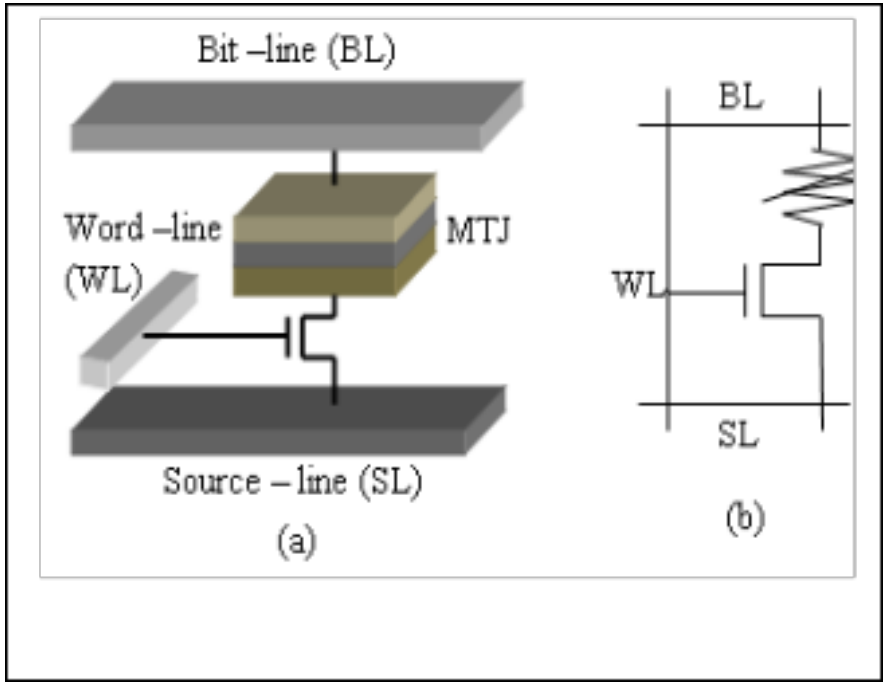




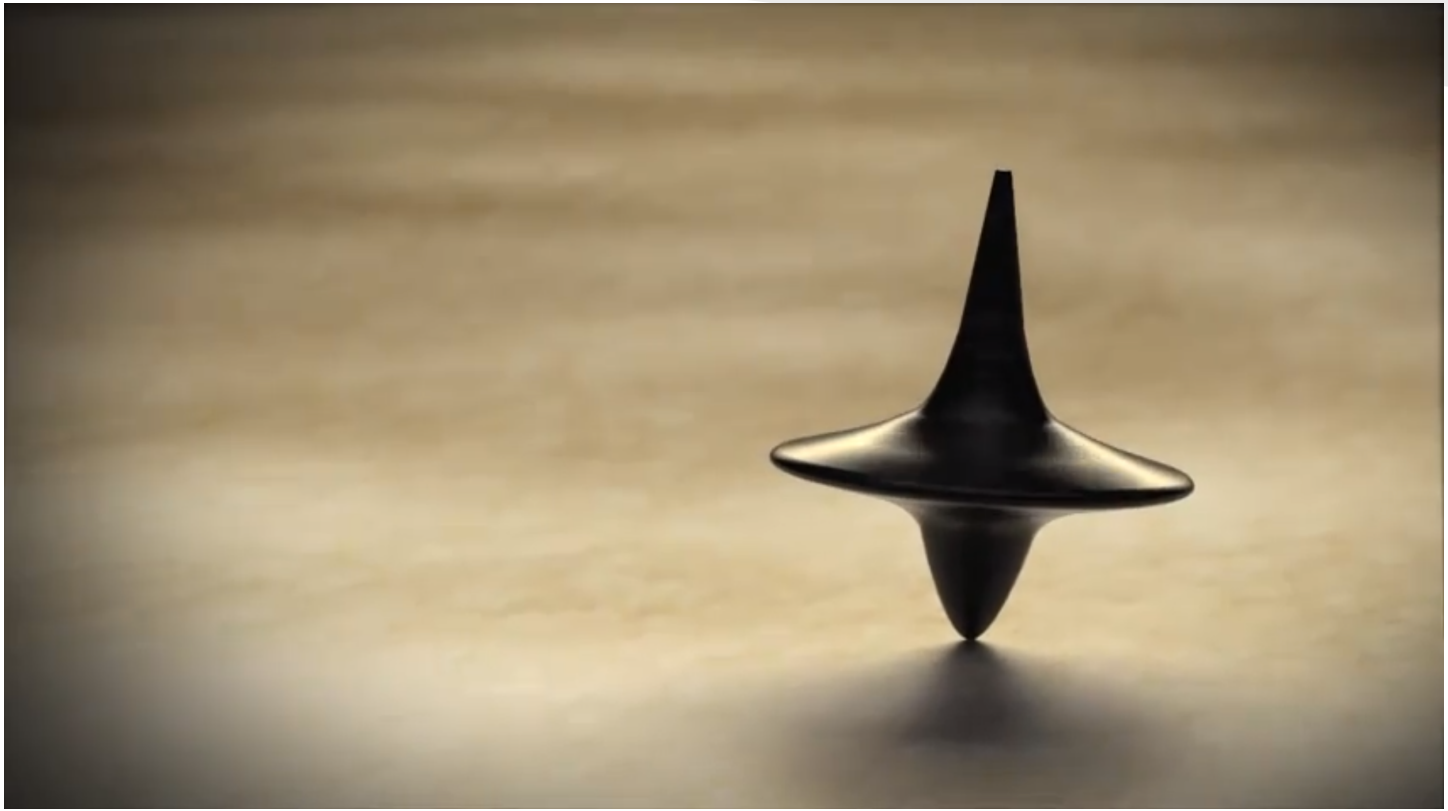
MTJ resistance states can be changed by an applied current.



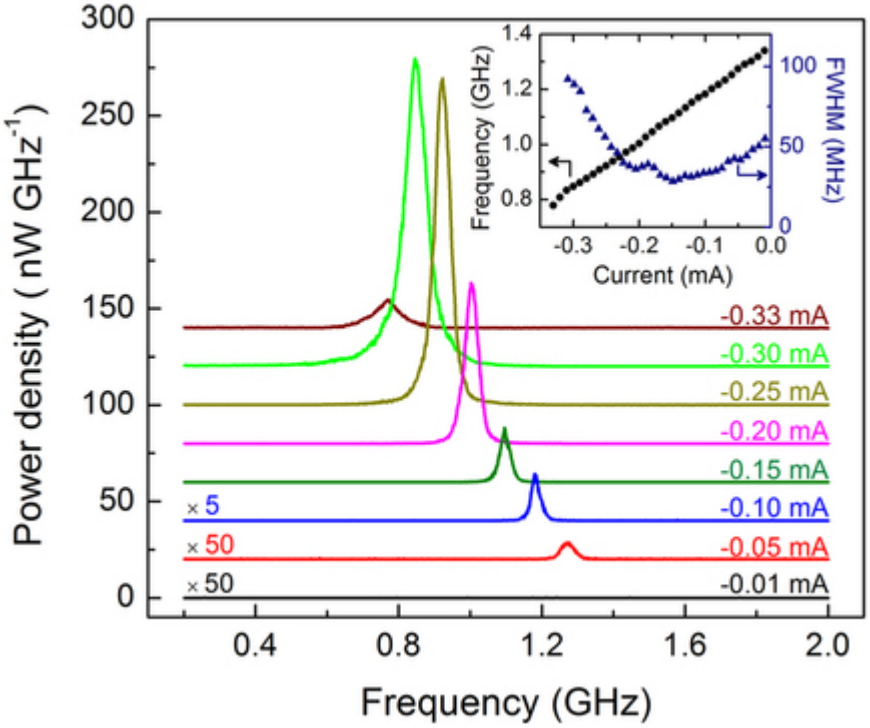
This property allows MTJ's to be used in memory applications, like STT-RAM.



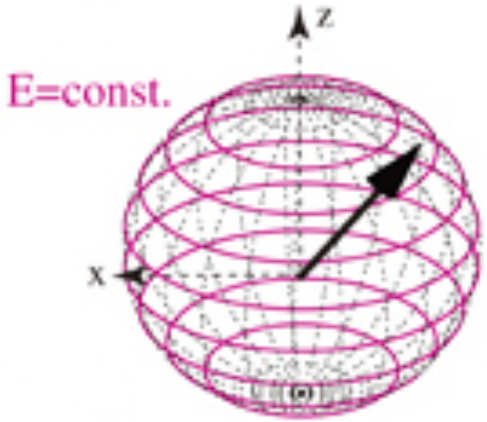
Spin Torque Nano Oscillators

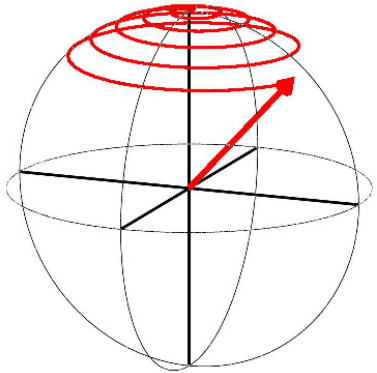


MTJs output various AC currents at different frequencies based on DC biasing.

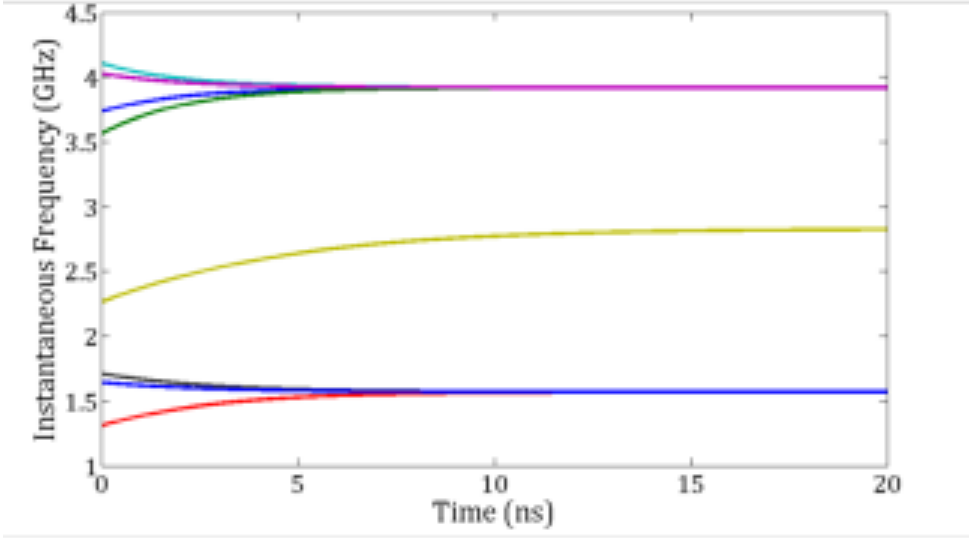


This oscillation stems from the intrinsic property of MTJ switching, called “precession.”

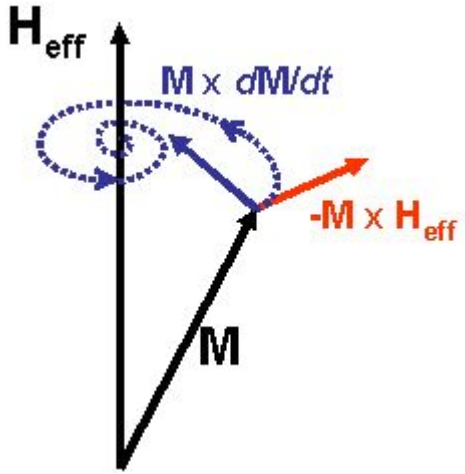




There is an inherent problem with STNOs… they take time to stabilize their oscillations.



The model we used for the MTJ and STNO was developed by Mehdi Kabir and Mircea Stan at the University of VIrginia and is based off the Landau-Lifshitz-Gilbert Equation.



$$\frac{d\mathbf{M}}{dt} = -\gamma\left(\mathbf{M}\times\mathbf{H}_{\text{eff}} - \eta\mathbf{M}\times\frac{d\mathbf{M}}{dt}\right)$$

Applications

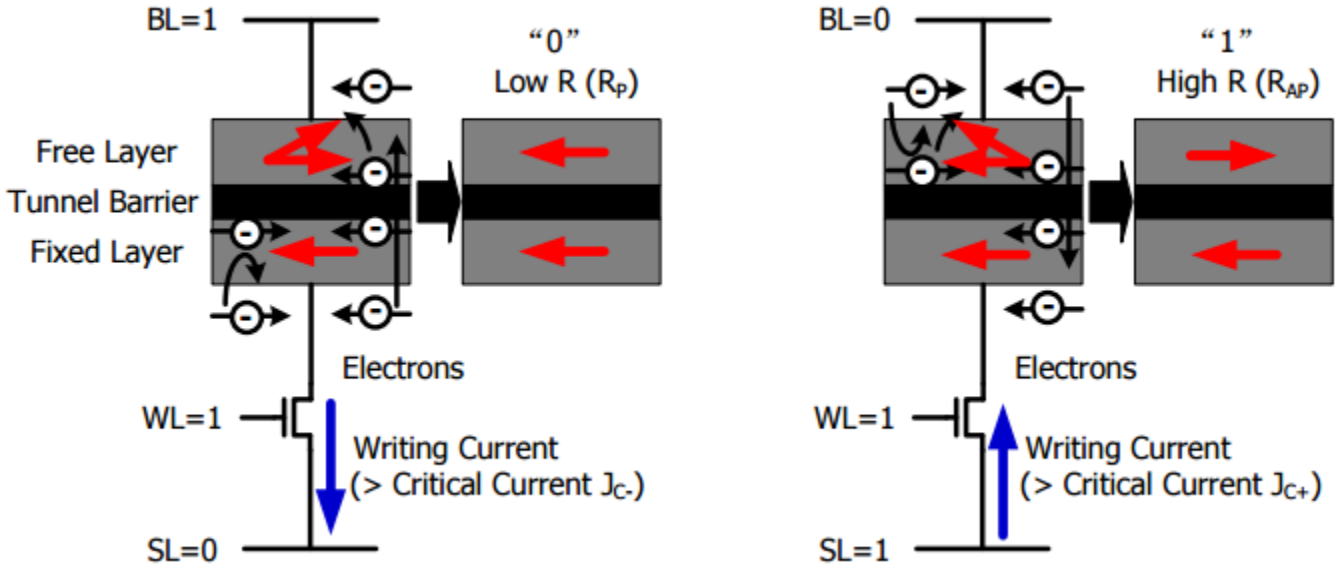
STT-RAM

Hybrid MTJ-CMOS Circuits

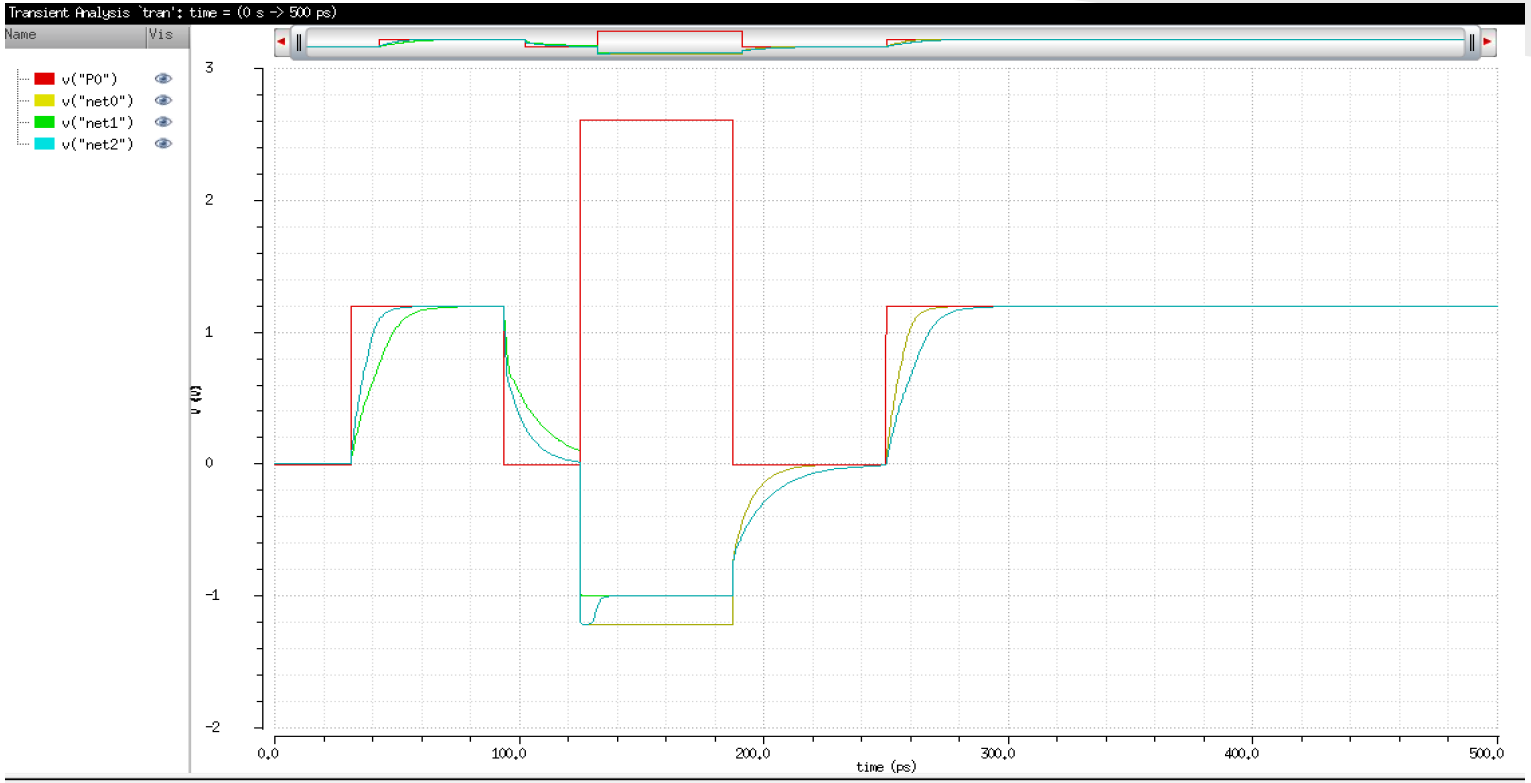
Microwave Signal Sources

RF Filters

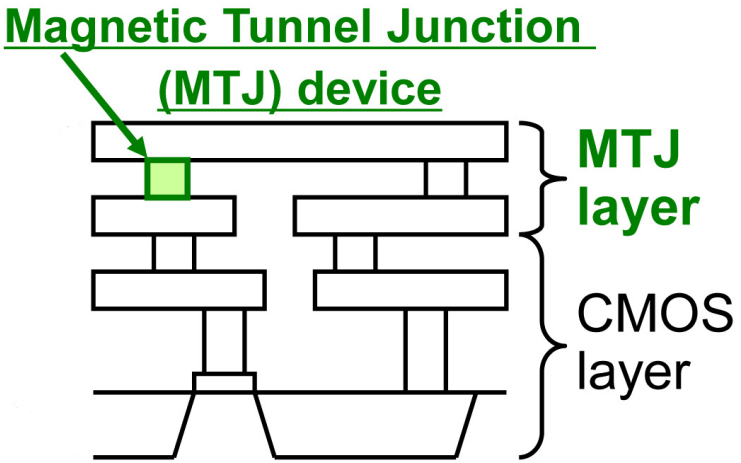
STT-RAM

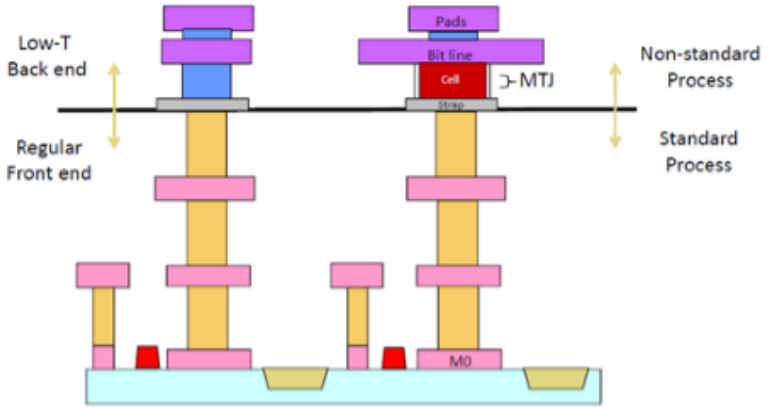

BL=1
"0"
Low R (R_P)
Free Layer
Tunnel Barrier
Fixed Layer
Electrons
WL=1
Writing Current
(> Critical Current J_{C-})
SL=0
BL=0
"1"
High R (R_{AP})
Electrons
WL=1
Writing Current
(> Critical Current J_{C+})
SL=1

STT-RAM R_P to R_{AP} Simulation



Hybrid MTJ-CMOS Circuits

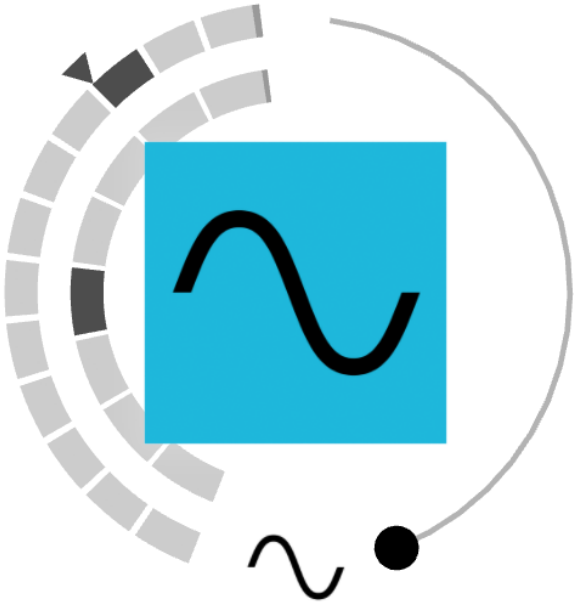


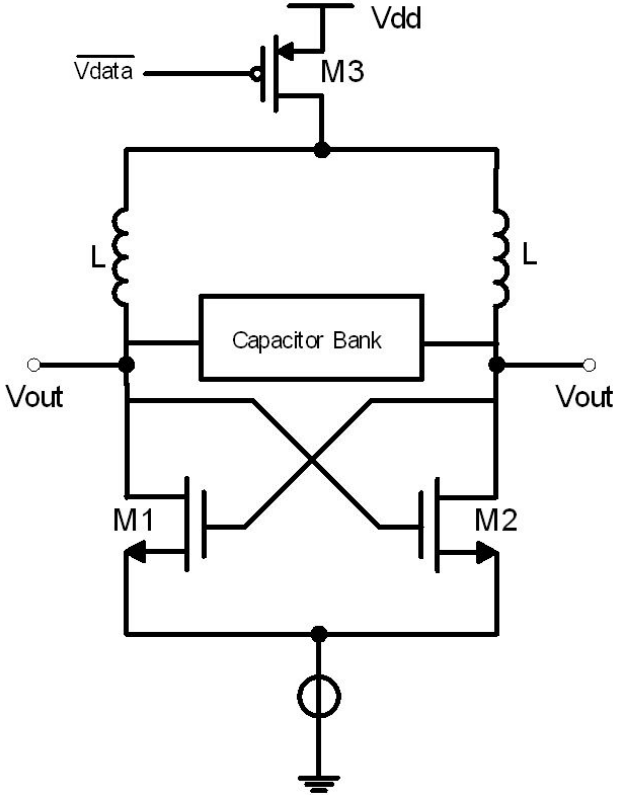


Hybrid MTJ-CMOS Circuits

- Register replacements (shadow memory)
- 2D memory arrays (LUTs)
- PLA

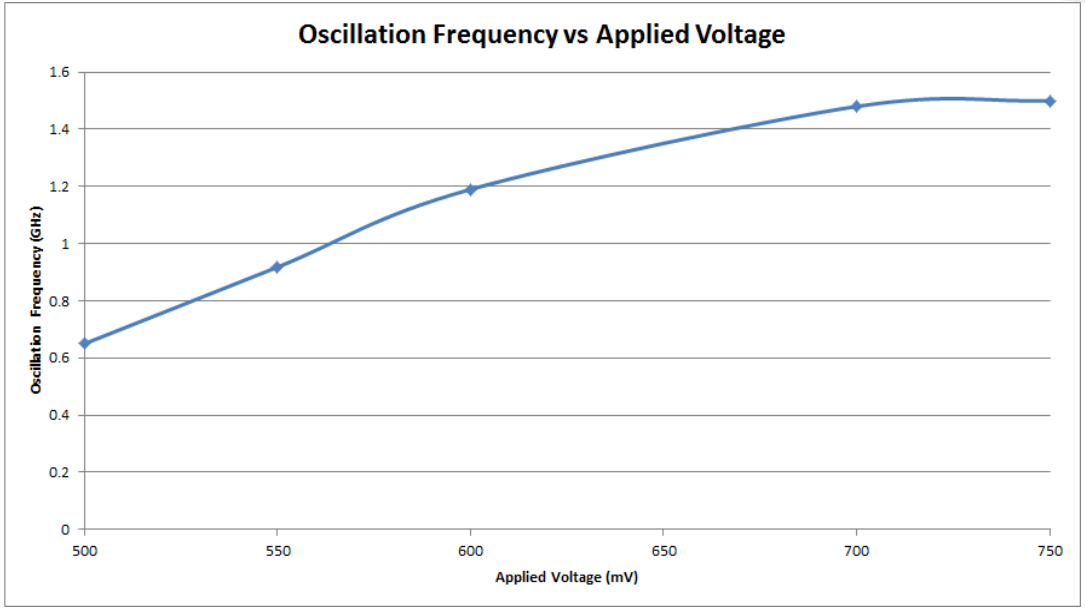
Microwave Signal Sources

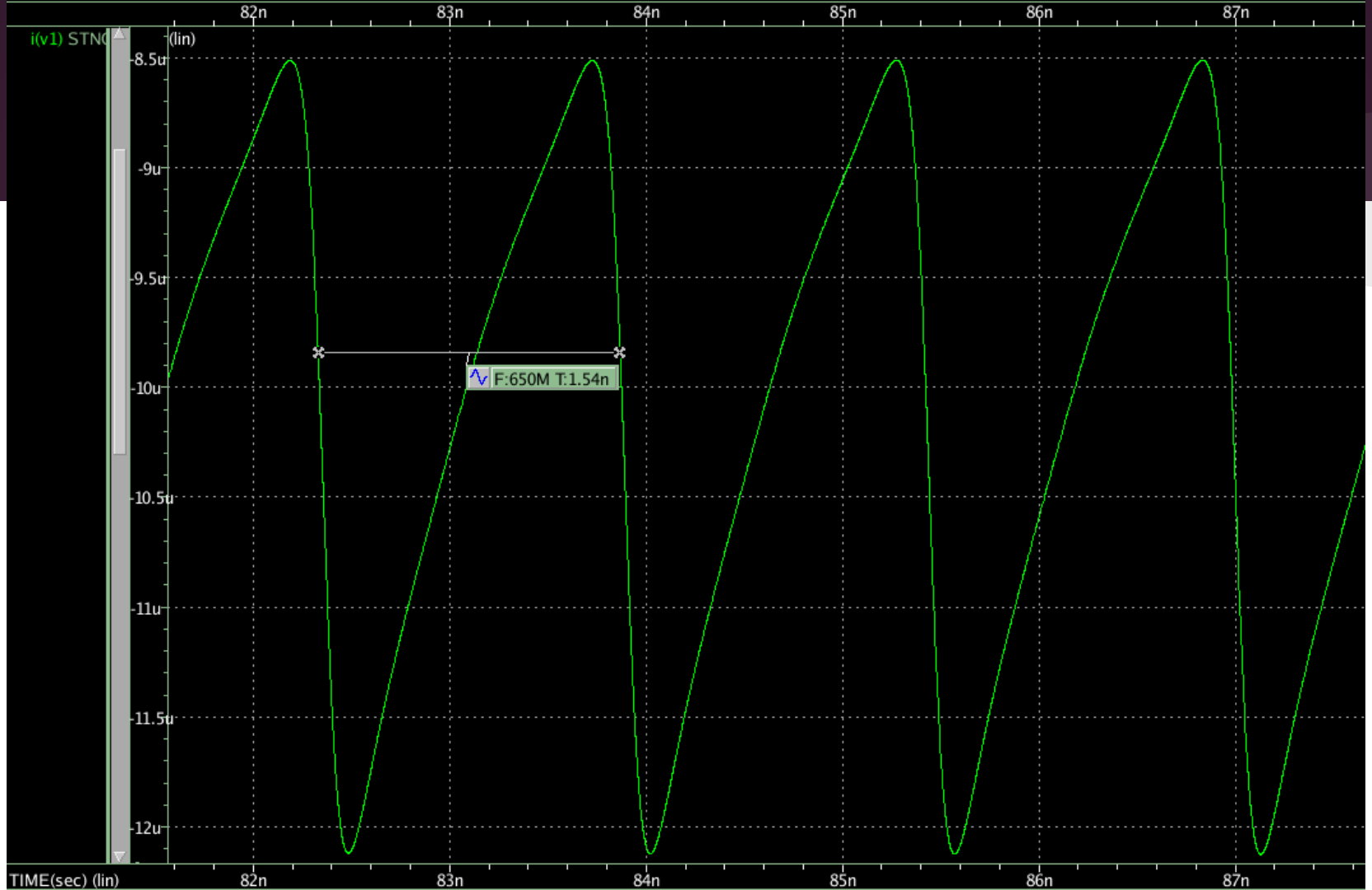


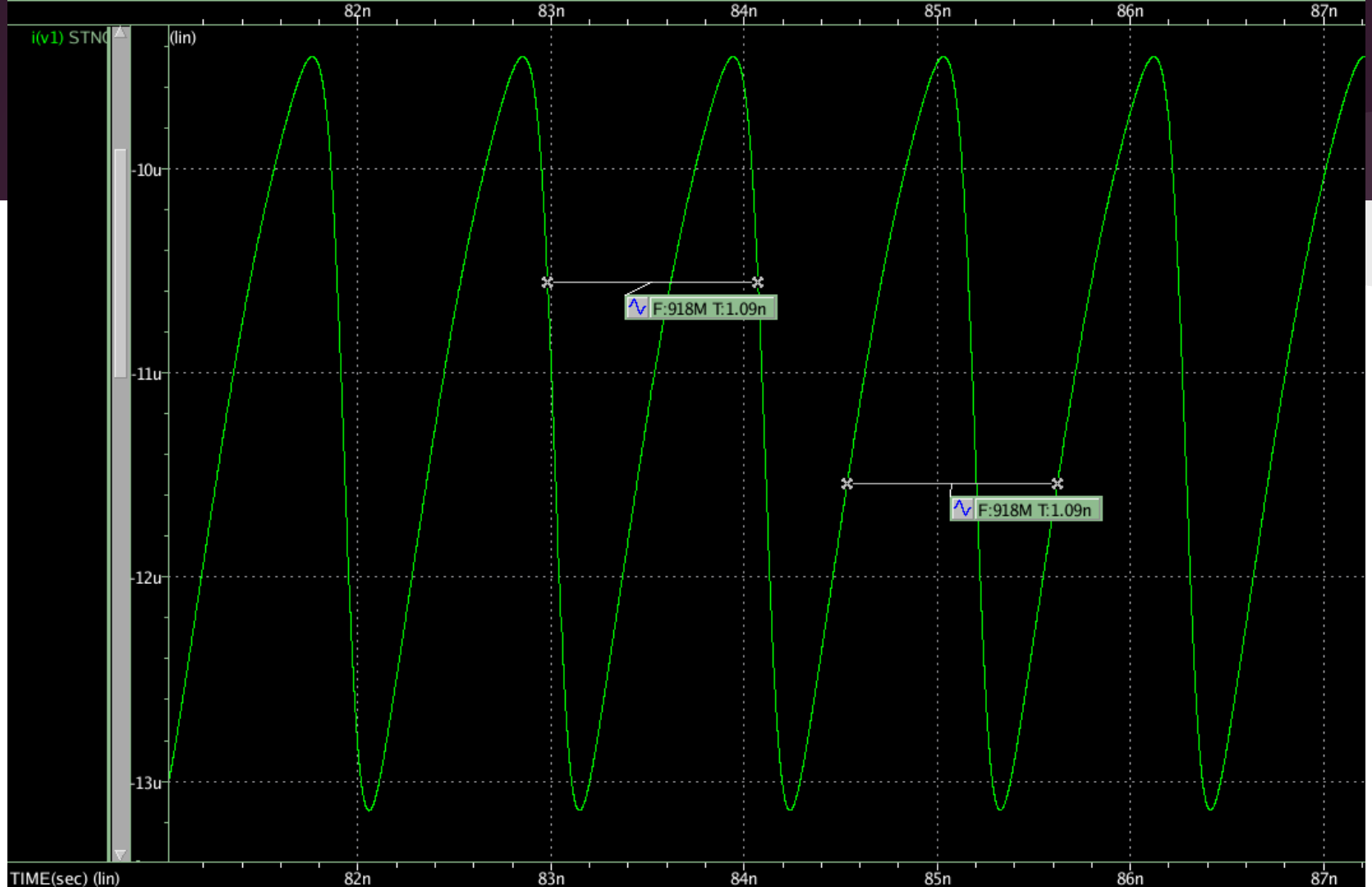


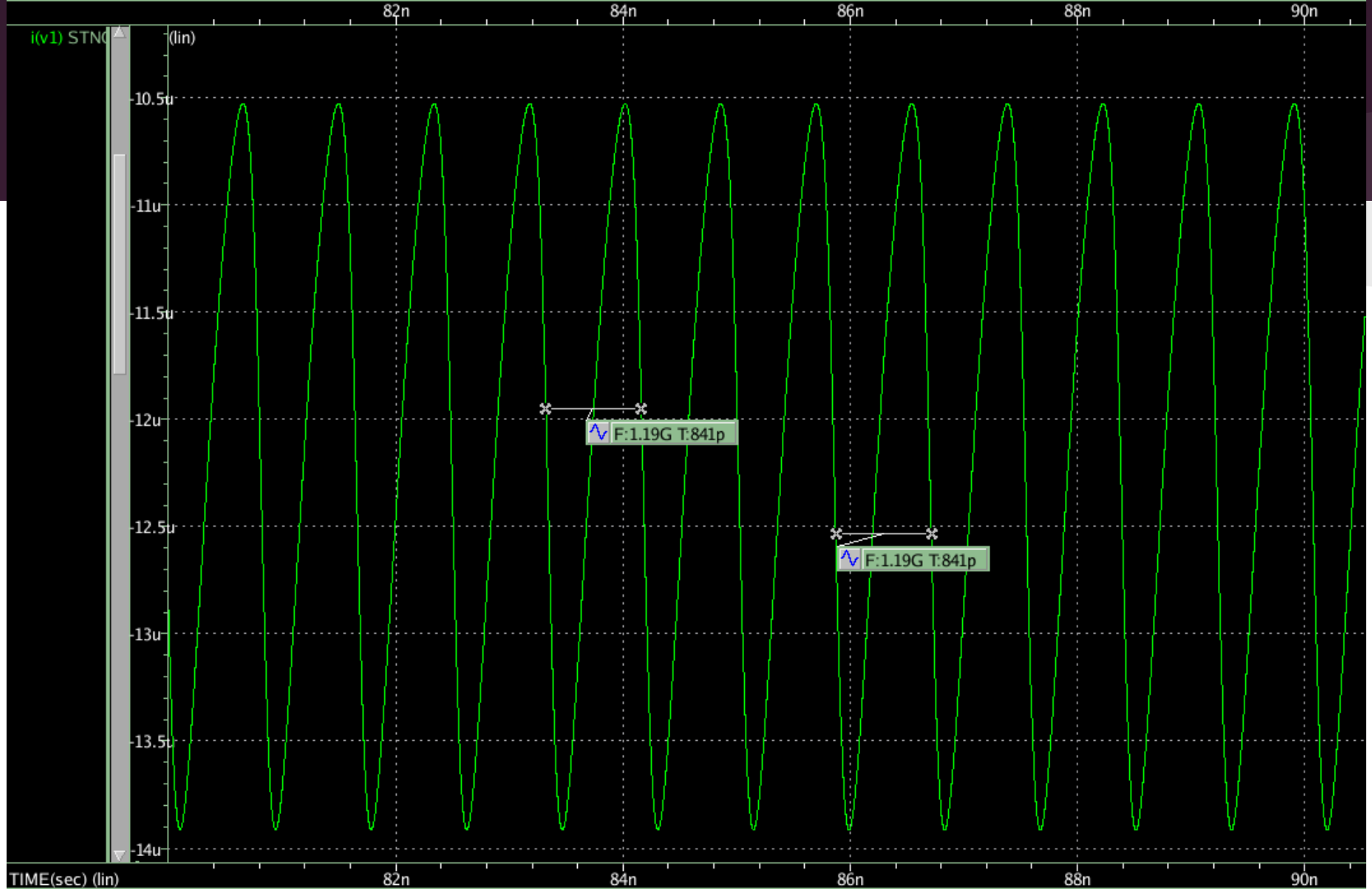
Simulations for Microwave Signal Sources

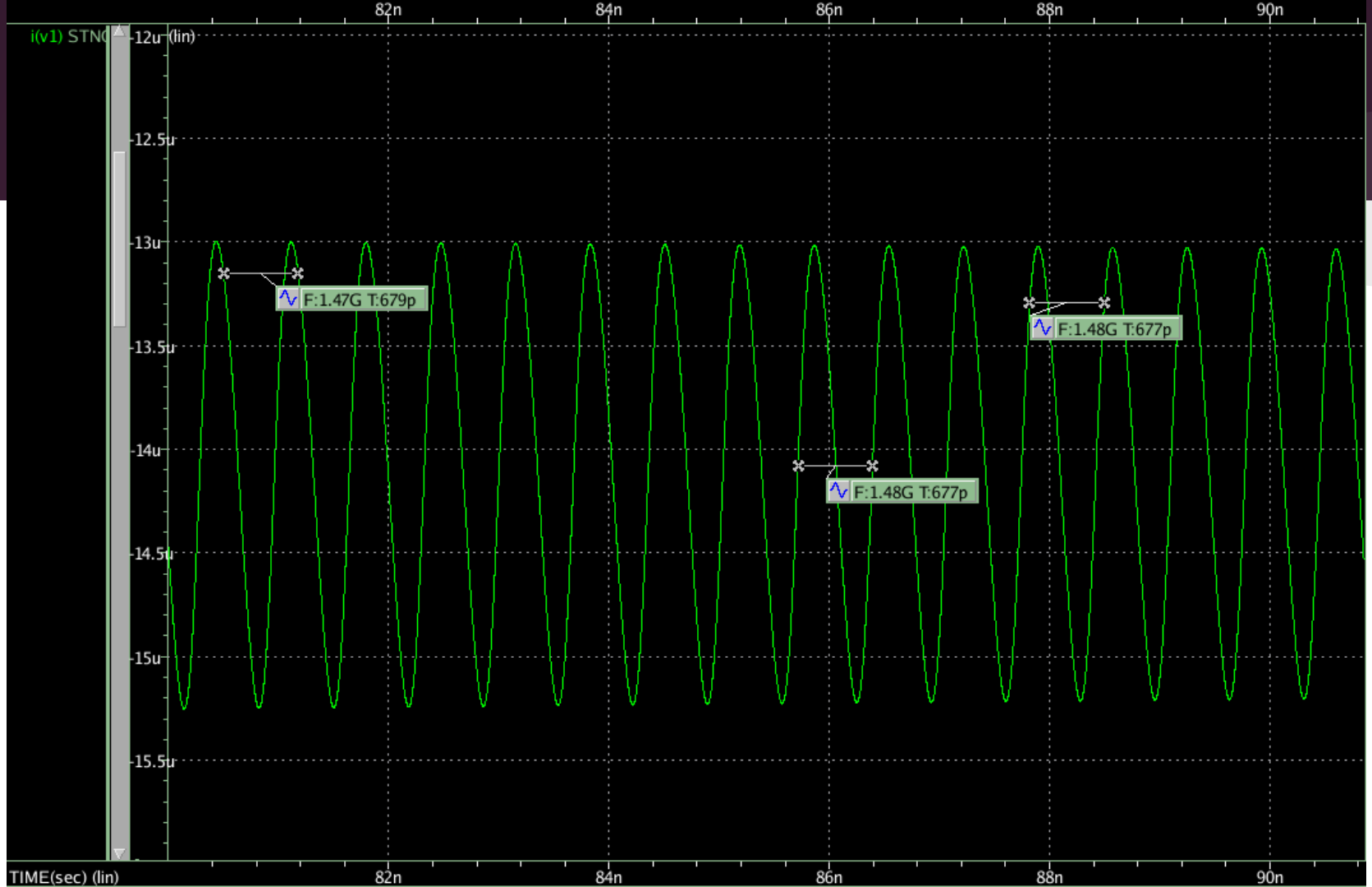
Applied Voltage (mV)	Oscillation Frequency (GHz)
500	0.650
550	0.918
600	1.190
700	1.480
750	1.500

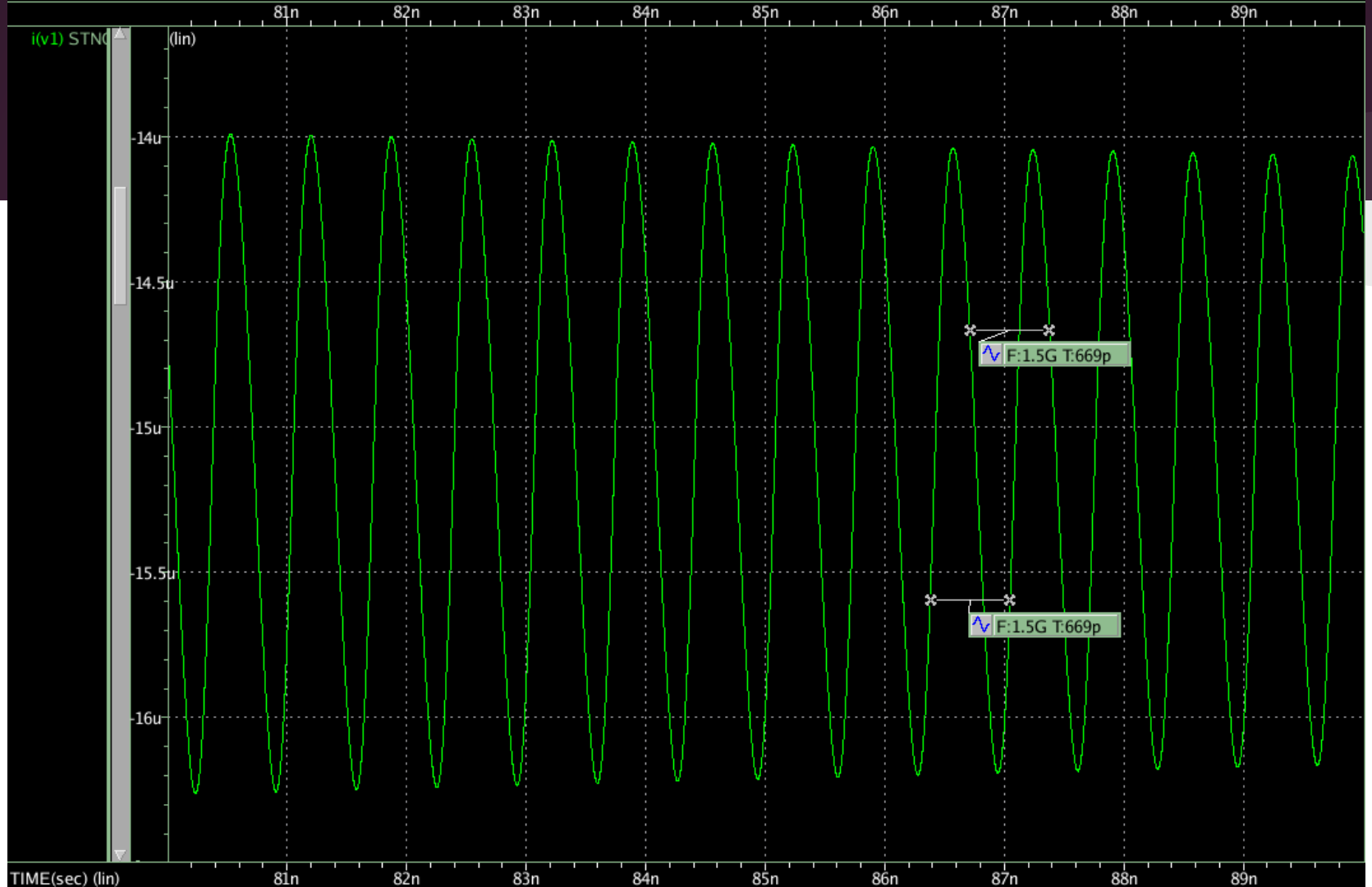


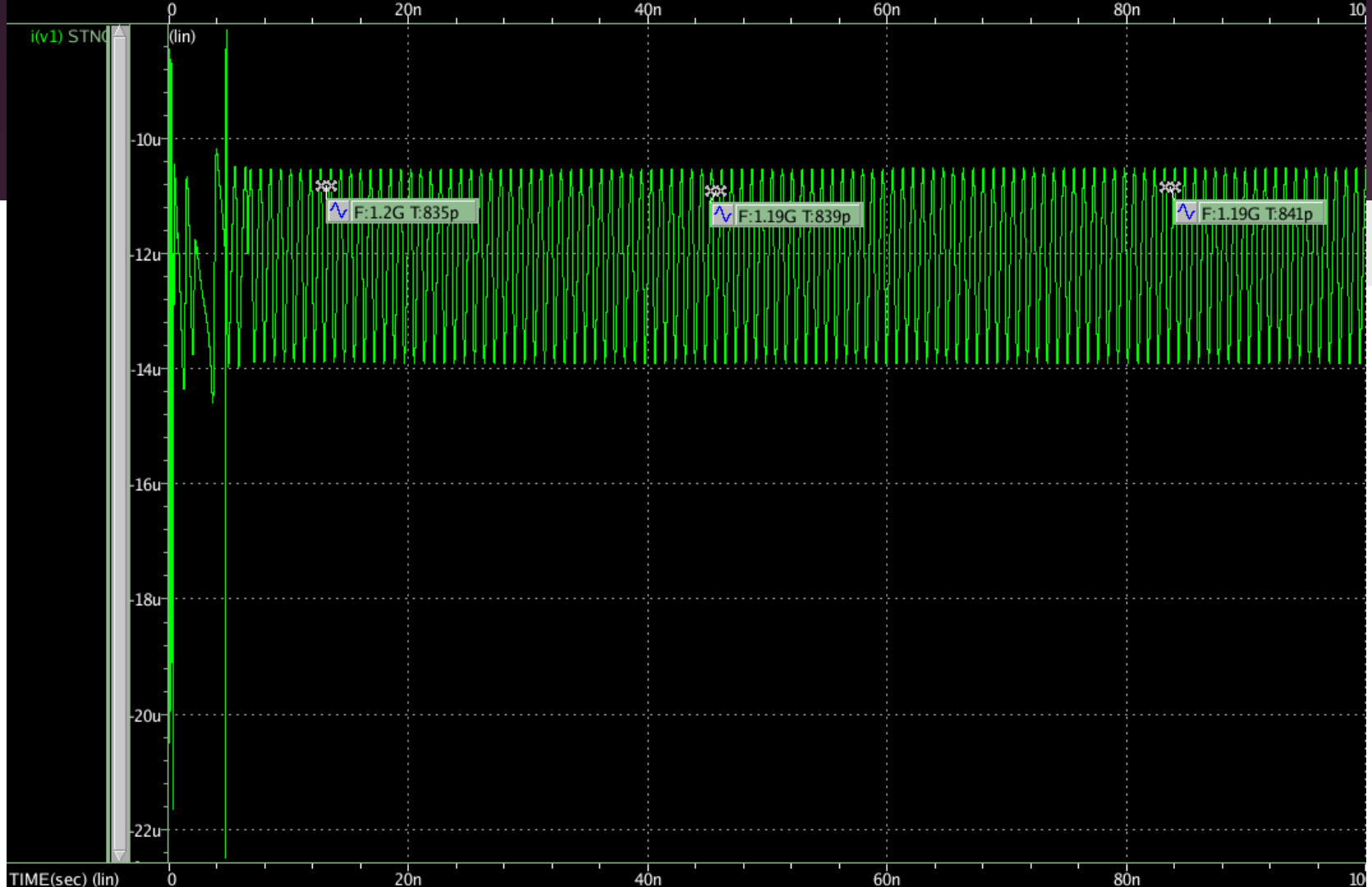

82n
83n
84n
85n
86n
87n
i(v1) STN
(lin)
-8.5u
-9u
-9.5u
-10u
-10.5u
-11u
-11.5u
-12u
F:650M T:1.54n
TIME(sec) (lin)


82n
83n
84n
85n
86n
87n
i(v1) STN(
(lin)
-10u
-11u
-12u
-13u
F:918M T:1.09n
F:918M T:1.09n
TIME(sec) (lin)


82n
84n
86n
88n
90n
i(v1) STN
(lin)
10.5u
11u
11.5u
12u
12.5u
13u
13.5u
14u
F:1.19G T:841p
F:1.19G T:841p
TIME(sec) (lin)


82n
84n
86n
88n
90n
i(v1) STN
(lin)
12u
12.5u
13u
13.5u
14u
14.5u
15u
15.5u
F:1.47G T:679p
F:1.48G T:677p
F:1.48G T:677p
TIME(sec) (lin)

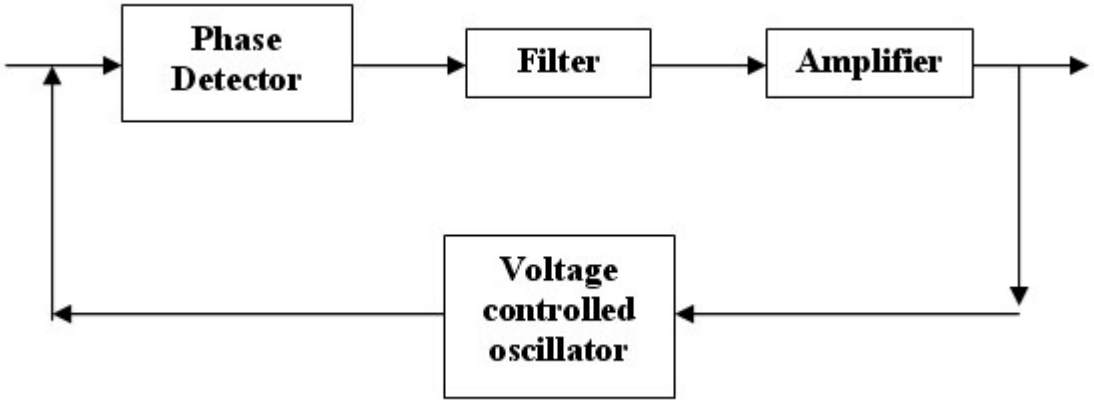

81n
82n
83n
84n
85n
86n
87n
88n
89n
i(v1) STN
(lin)
-14u
-14.5u
-15u
-15.5u
-16u
F:1.5G T:669p
F:1.5G T:669p
TIME(sec) (lin)


i(v1) STN
(lin)
0
20n
40n
60n
80n
10
-10u
-12u
-14u
-16u
-18u
-20u
-22u
F:1.2G T:835p
F:1.19G T:839p
F:1.19G T:841p
TIME(sec) (lin)

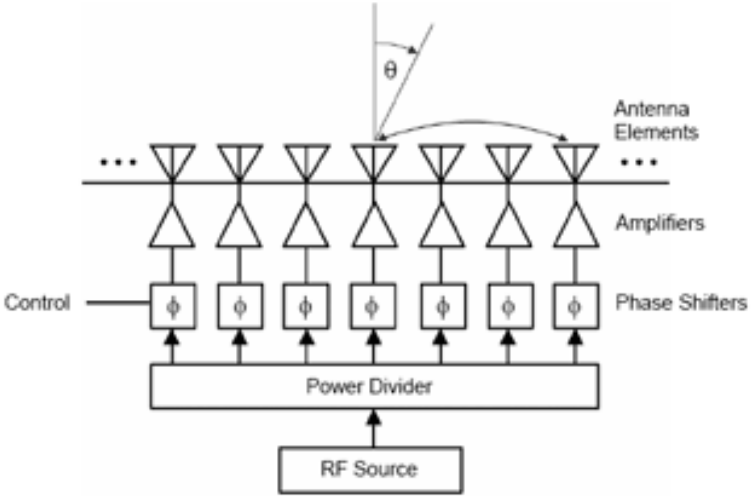
Phase Locked Loop (PLL)

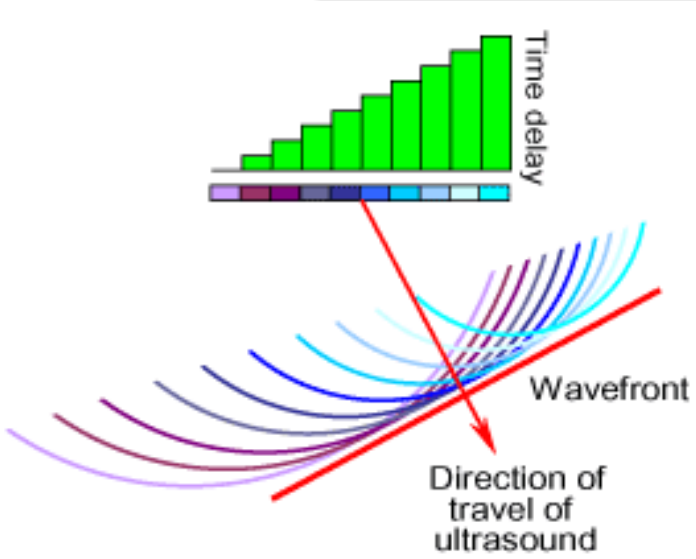
Current research utilizes oscillations of 100nA, amplified through a transimpedance amplifier to generate highly stable phase-locked oscillators.

STNO's offer tunability.



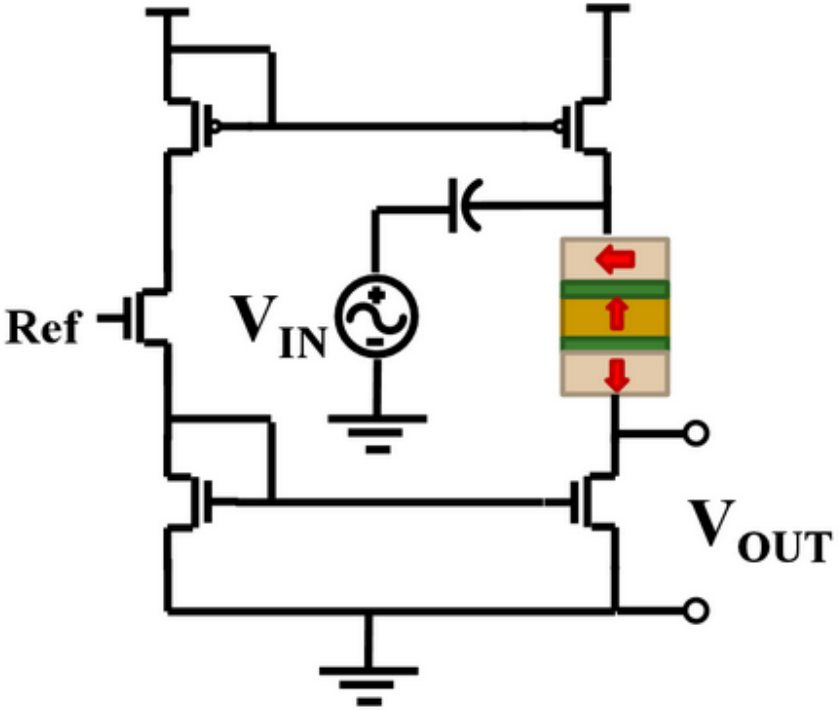
Phased Arrays

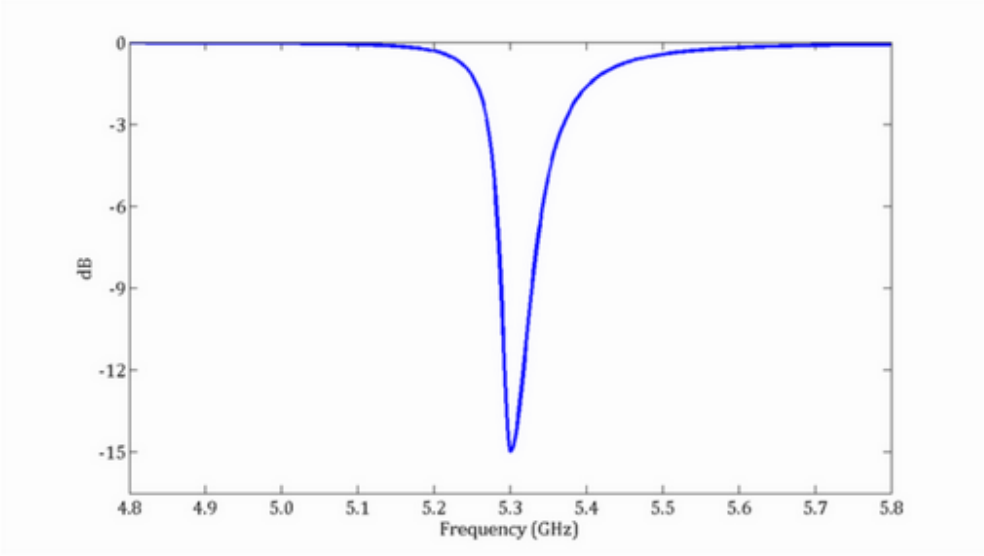




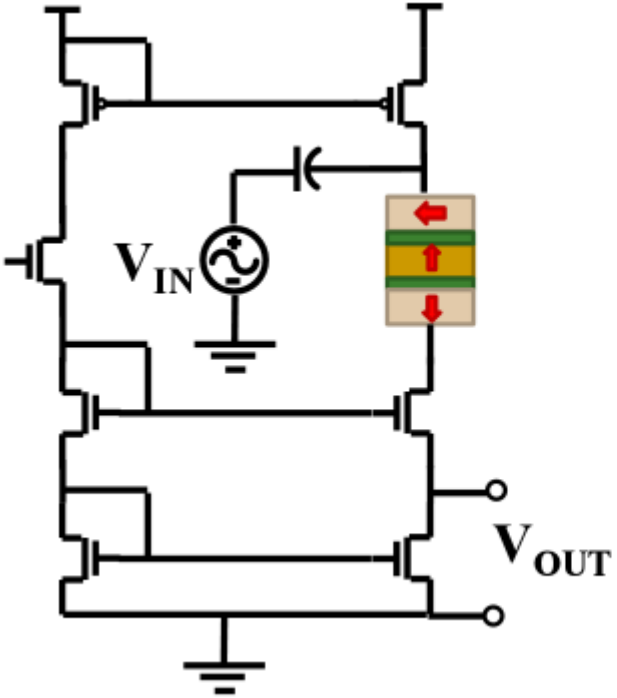
Lincoln Labs is working on a phased array with an input of 1.3GHz. Tuning circuitry adds phase noise and destability.

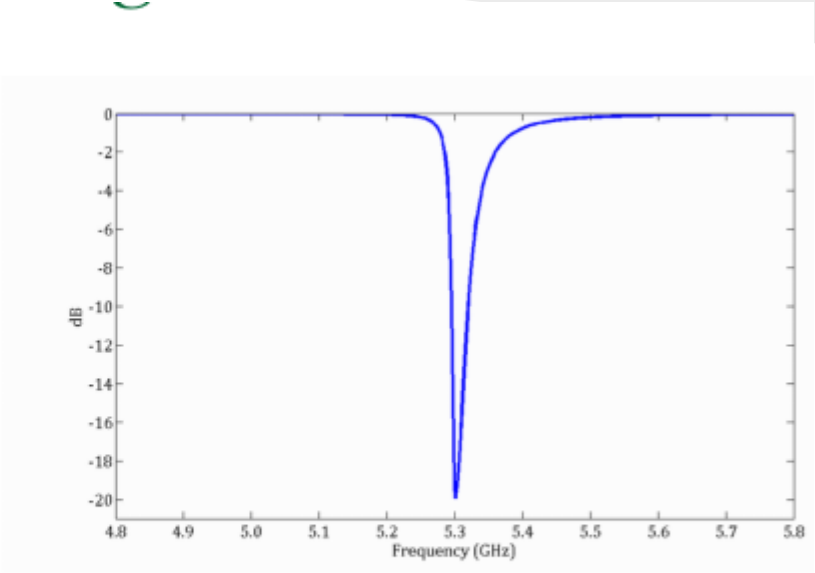
STNO RF Filters (Narrow Notch)





STNO RF Filters (Current Mirror)





Other Applications

- Base Station
  - Filter out spurs
- RF Test Equipment
  - Need wideband LO for spectrum analyzer
- Stealth Detection

What conclusions can be drawn?

Many applications exist where MTJs and STNOs can potentially outperform traditional oscillators

- On-chip integration
- Wide (and simpler) tunability
- Low power and high Q

Acknowledgements

We would like to thank Professor Stan and Mehdi Kabir for all their help with this project.

Resources

http://conservancy.umn.edu/bitstream/handle/11299/119363/Yao_umn_0130E_12376.pdf?sequence=1

http://www.spintec.fr/-Spin-Transfer-based-RF-oscillators-

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